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DISTRIBUTION OF SURFACE PRESSURES WITH REGARD TO AVOCADO FRUIT AT THE CONSTANT LOAD VALUE

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ABSTRACT

Researches, which were carried out, present results of measurements of surface pressure of Avocado Fuerte cultivar in the radial compression test between flat panels at the constant load value including time factor. The test was carried out with the use of Instron 5566 testing machine. On the bottom panel, under the compressed Avocado fruit a sensor of Tekscan system number 5076 was placed. It allowed a constant observation of contour lines of surface pressures on the contact surface and determination of distribution of surface pressures between Avocado and a bottom panel of the testing machine. Contour layers and distribution of surface pressures in different stages of the creep test were determined. It was proved that maximum and average values of the surface pressures are subject to minimum changes during the entire test. Distribution of surface pressures has a shape typical for contact issues in the elastic scope of deformation, where maximum values are in the central zone of contact and are distributed similarly to the even number curve. At the end of the test, distribution of thrusts on the contact surface of Avocado with a working element of the testing machine took place at the end of the test.

Introduction

Avocado from the Lauraceae family occurs in the tropical and subtropical climate of America. In South America it has been known for thousand years. Avocado spread fast from North America through Central America as far as South America. The main exporters are Peru, Chile and Mexico, New Zealand and South Africa. In the USA plantations are located in California and in Florida. Orchards produce at the average seven tonnes per hectare annually and some even reach 20 tonnes per hectare. An avocado tree does not tolerate low temperatures and may be cultivated only in the subtropical and tropical climate. There are several cultivars, which are cold resistant and they are planted in the region of Gainesville in Florida and are able to survive temperatures even up to -6ºC.

Avocado fruit is pear shaped. A thick green exocarp surrounds thick, cream-green pulp (mezocarp) and an inedible seed. Avocado is a calorific fruit. It contains 160 kcal in 100 g. Its fat profile is a unique feature. It contains 15.3 g of fat in 100 g. However, these are monounsaturated fats and omega 3 acids. Avocado may be used interchangeably with butter or margarine. It is a plant product thus it does not contain cholesterol and has a lower content of calories compared to fat products. Nutritive value of avocado comprises vitamins A, B1, B2, C, PP, K and, pantothenic acid, carotenes, protein and mineral substances: calcium, potassium and phosphorus.

Although there are over 500 cultivars of avocado fruit, cultivars are focused in three basic groups:

– Mexican breed - (Central Mexico) with small fruit (2.5-7.5 cm of length), pulp has a walnut taste and anise smell; it contains 29% of fat. It is a cultivar which is frost-resistant, of pink and brown colour.
– Antilles breed with bigger fruit (Antilles) (7-25 cm of length). Requires warmth and moisture. It has green and yellow-coloured fruit
– A guatemala breed - (Guatemala), a fruit with a similar size but with a lower content of fat (5-14%) with a water taste, yellow to brown-mahogany colour (www.itum.com.pl).

On account of nutritive values, avocado has become an important raw material in the food industry. During transport and storing fruit are exposed to mechanical damages, which may lead to the lowering of their quality and may cause losses to growers and exporters. Knowing the behaviour of Avocado fruit influenced by external forces may lead to new solutions which aim at improvement of the products quality. Care for raw material may decrease losses on the domestic market which translates into a higher profitability of production (Nadulski, 2009; Płocharski et al., 2000).

On account of the Avocado fruit shape, a significant role in carrying loads in harvesting, transport and storing processes is played by surface pressures. The contact issues are one of the most complex problems related to resistance of not only biological materials. One of the methods used in practice in calculation of surface pressures is based on Hertz formulas. Using these formulas for plant materials has no theoretical justification. Despite this, some authors' research proved that the use of Hertz's theory may in many cases lead to formulation of trustworthy indexes which describe surface pressures or the time of contact, although errors may reach as much as 20% (Rabelo, 2001; Siyami et al., 1988). Model research, which cover the issue of surface pressures of carrot roots constructed with the use of MES show that the model tests results correspond well to real values (Stopa, 2011).

Tests on the strength properties of avocado fruit were carried out by Edward A. Baryeh (2002) who showed that directly at harvesting they are very high but get worse as soon as after 7 days. Impact tests were carried out and they proved that at the test of free falling from 0.5 m height directly after harvesting – 25% of fruit were damaged, whereas after 15 days of storing – 90% were damaged. He also stated that fresh fruit may be packed into wooden boxes up to 35 layers but as soon as after 15 days only two layers are recommended. In his paper Herold et al. (2001) used Tekscan system, which allows the measurement of the surface thrust distribution on the entire surface of contact of the loading element with the investigated object. Another method indispensable at determination of surface thrust was suggested by (Lewis, 2008). It consisted in the use of an ultrasound wave.

Van Zeebroeck (2003) prepared discreet models with the method of finite elements which allow determination of the transport conditions impacts on the losses due to damage to apples. Modelling with the finite elements method was also carried out by M. Valente et al. (1996) investigating the heat exchange during drying of avocado.

Objective of the research

The objective of the research was determination of contour layers and distributions of surface pressures of Fuerte avocado as a function of time in the radial compression test and determination of changes of the surface thrust values as a function of time in the central contact zone.

Methodology and object of the research

The research was carried out in the Laboratory of Agrophysics of the Institute of Agricultural Engineering of the Wroclaw University of Environmental and Life Sciences. A testing machine INSTRON 5566 equipped with a tensometric head with a measurement scope up to 1 kN was used in the research. It allowed measurement of power with precision up to 1 N and displacement with a precision up to 0.05 mm. The machine was controlled by a computer with the installed BlueHill programme allowing registration and analysis of the results of research. The speed of the head movement to the moment of reaching an assumed value of initial loading was 1.8 $mm \cdot min^{-1}$.

Fuerte cultivar of Avocado from Peru was used in the research. Fruit were bought in Poland. Healthy items were selected with similar dimensions and mass from 180 to 220 g. During measurement constant moisture of raw material was maintained.

Firstly, measurements aiming at determination of border values of loading in the compression test were carried out. The value of the destructive force F_{max} was determined. It was the basis for calculation of the value of the initial loading of avocado F_0 and a corresponding value of the initial movement of the element, which loads the testing machine Instron 5566.

From the point of view of the contact issues with reference to the biological materials the basic problem when determining the surface pressures, is a measurement of the surface area of contacting bodies and the value of the pressure force. The presented research applied a method based on the use of Tekscan system, which allows permanent observation of the changes of the contact surfaces of avocado and working elements of the loading device, the pressure force and surface pressures. Measurements were carried out at three values of initial loading in 5 repeats. After the initial research, the measurement time was assumed at the constant value of loading which was 1200 s. The increase of the measurement time over 1200 s did not affect the nature of changes of surface thrust values as a function of time.

Figure 1. Tekscan measuring system

The Tekscan system consists of the foil sensor, a grip, a distributor and the computational programme which allows registration of the research results carried out at the frequency of sampling of approx. 1000Hz. It also allows later analysis of the collected data. 5076 sensor (fig. 1 table 1) built of the system of parallel electrodes divided with a layer of polyester foil was used for the research. In the place where the electrodes were crossing, they formed sensors which allowed determination of the value of the loading force and the surface area of the contact of avocado fruit with a working element of the testing machine. During the measurement, changes of the surface area of the contact, values of the pressure force and contour layers of surface areas as a function of time, were registered.

Table 1
Technical data of plastic sensor 5076

Dimensions of a sensor		Lengthwise direction		Transverse direction		Number of sensors (item)	Density of sensors (item·cm$^{-2)}$
Length (mm)	Width (mm)	Spacing (mm)	Numb er of (item)	Spacing (mm)	Numb er of (item)		
83.8	83.8	1.9	44	1.9	44	1936	27.6

Source: www.tekscan.com

Errors related to the shape of samples, measurement of the pressure force and determination of the contact surface constituted a part of the total error of experimental determination of the surface area of the contact of an avocado sample with the ground. On account of very careful preparation of samples for research, the error of shape as a systematic error may be omitted. Measurement of force, measurement of the surface area of contact and the value of surface pressures was determined with the use of the Tekscan system of the following parameters: system precision <±4%, blinearity error<±3%, repeatability of results<±3.5%, hysteresis<±4.5% and creeping: <5%.

Research results and their analysis

Based on the compression test, values of the maximum force, which cause destruction of the tested fruit, were determined and on this basis initial loading of samples F_0 and the corresponding shift of the loading element Δl_0 were defined (tab. 2). The compression test was carried out for five repeats at the speed of movement of the measurement head which is 1.8 $mm \cdot min^{-1}$. The maximum force F_{max} which is 674 N and corresponding movement Δl_{max} which is 23.9 mm was obtained. Based on the obtained data, values of the initial loading of fruit were calculated (table 2).

Table 2
Initial parameters of the compression process

Initial parameters	Initial loading	Initial movement
10% F_{max}	F_{010} =67.4 N	Δl_{010} =2.39 mm
20% F_{max}	F_{020} =134.8 N	Δl_{020} =4.78 mm
30% F_{max}	F_{030} =202.2 N	Δl_{030} =7.07 mm

Exemplary results of research obtained in the compression test of Avocado fruit for the initial value of the loading force which is 20% F_{max} will be presented (table 2).

Figure 2 presents the course of changes of the measurement head of the testing machine instron as a function of time. The process of creeping started after 190 seconds from the moment of starting the measurement after reaching the complex loading F_{020} =134.8 N at the head movement Δl_{020} = 4.78 mm. In the final phase of test after 1,200 seconds the shift reached the value of Δl =5.58 mm, which means that the average speed of the creeping process is 4.7 10^{-2} $mm \cdot s^{-1}$.

The change of the value of mean surface pressures in the contact zone of avocado fruit with an element which loads the testing machine during the test is presented in figure 3. In the moment, the test started, mean surface pressures reached the value of p=0.328 MPa and afterwards were gradually reduced to the level of p=0.309 MPa after 500 seconds and p=0.295 in the end of the test. It means that within 190 to 500 seconds the surface pressures were decreasing in the rate of 612 10^{-6} MPa·s^{-1} whereas within 500 to 1200 seconds the rate was 20 10^{-6} MPa·s^{-1}.

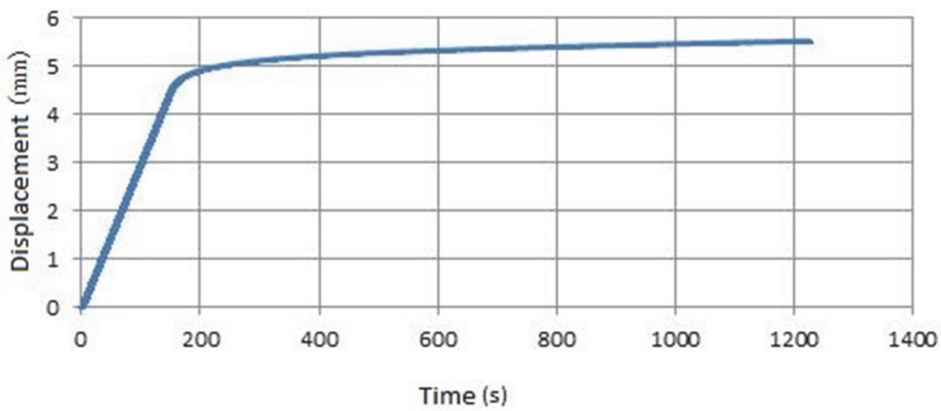

Figure 2. Course of the creeping process

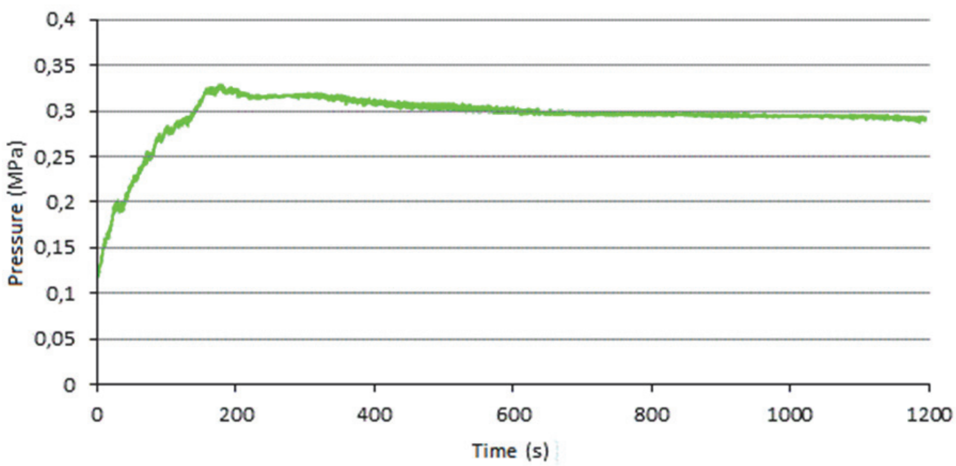

Figure 3. Average values of surface pressures as time function Δt=0 to 1200s

Figure 4 presents contour layers and distribution of surface pressures of avocado Fuerte cultivar after time of t=78 s from the moment the test begins, during reaching the assumed value of the initial loading F_{020} =134. N.

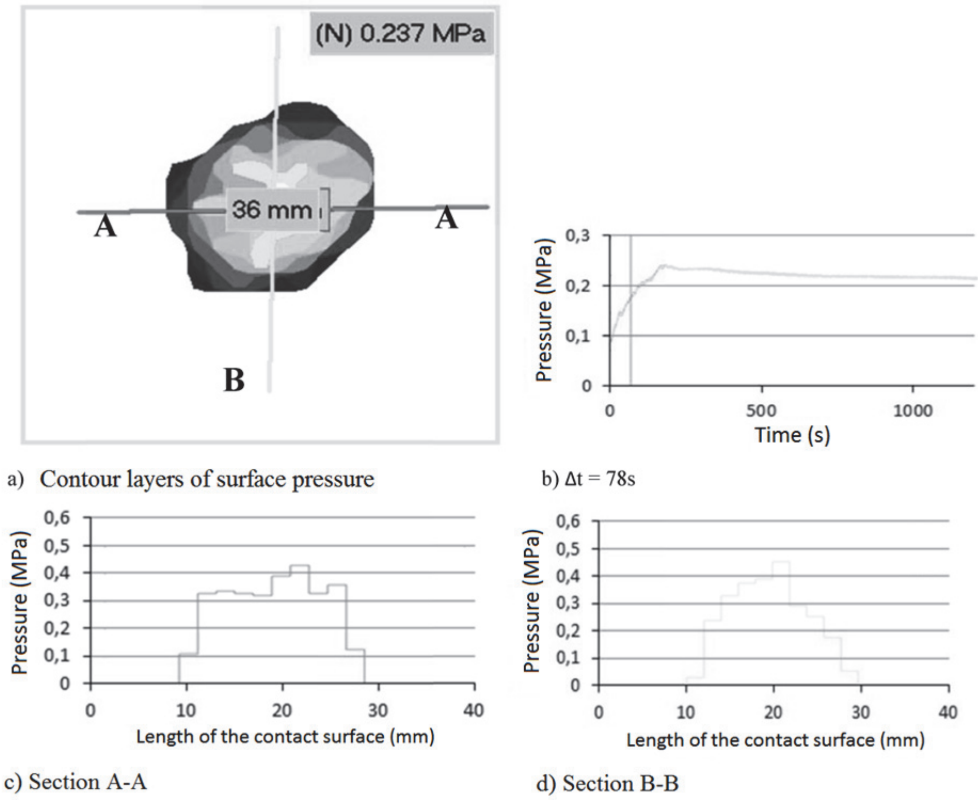

Figure 4. Contour layers and distribution of surface pressures in time Δt=78 s

Contour layers of the surface pressures indicate a point nature of the loading element impact on the avocado fruit (figure 4a). Average values of surface pressures are 0.237 MPa while the maximum values which are in the central point of contact are 0.451 MPa (fig. 4c,d).

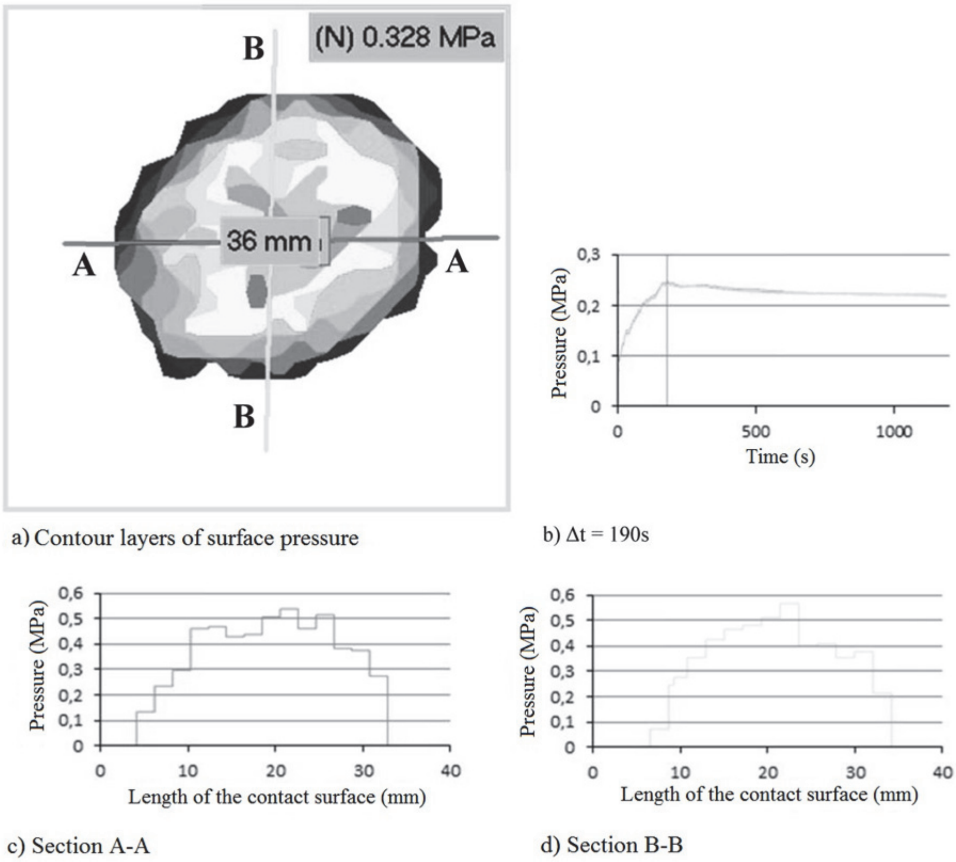

Figure 5. Contour layers and distribution of surface pressures in time Δt=190 s

With the beginning of the creeping process after 190 seconds from the moment the test begins and after the assumed value of loading F_{020}=134.8 N (fig. 5a) begins, the nature of impact of the working part of the testing machine on the Avocado fruit did not significantly change. The maximum surface pressures are in the central contact zone (fig. 5 c, d). Only their values increased to the level of 0.574 MPa at the average which was 0.328 MPa and an explicit increase of the contact surface. It proves that the Avocado cells were not destroyed in the contact zone. One should assume that this phenomenon is caused by a slow movement of liquids in the zone with a higher pressure to zones with still empty intercellular spaces without destruction of cell walls.

Figure 6 presents contour layers and distribution of surface pressures of avocado after t=500 s from the moment the test begins. The surface area of avocado contact with a testing machine did not undergo any explicit change. Distribution of surface pressures along the contact surface is of a shape of an even curve. The maximum values of surface pressures decreased and they are p=0.509 MPa (fig. 6 c,d) at average values p=0.309 MPa. Surface pressures on the contact surface were not levelled and the maximum thrusts are still in the central zone of contact (fig. 6a). Such distribution of thrusts proves an elastic nature of deformation of the avocado pulp tissue and shows no destruction of cell walls in the process of creeping.

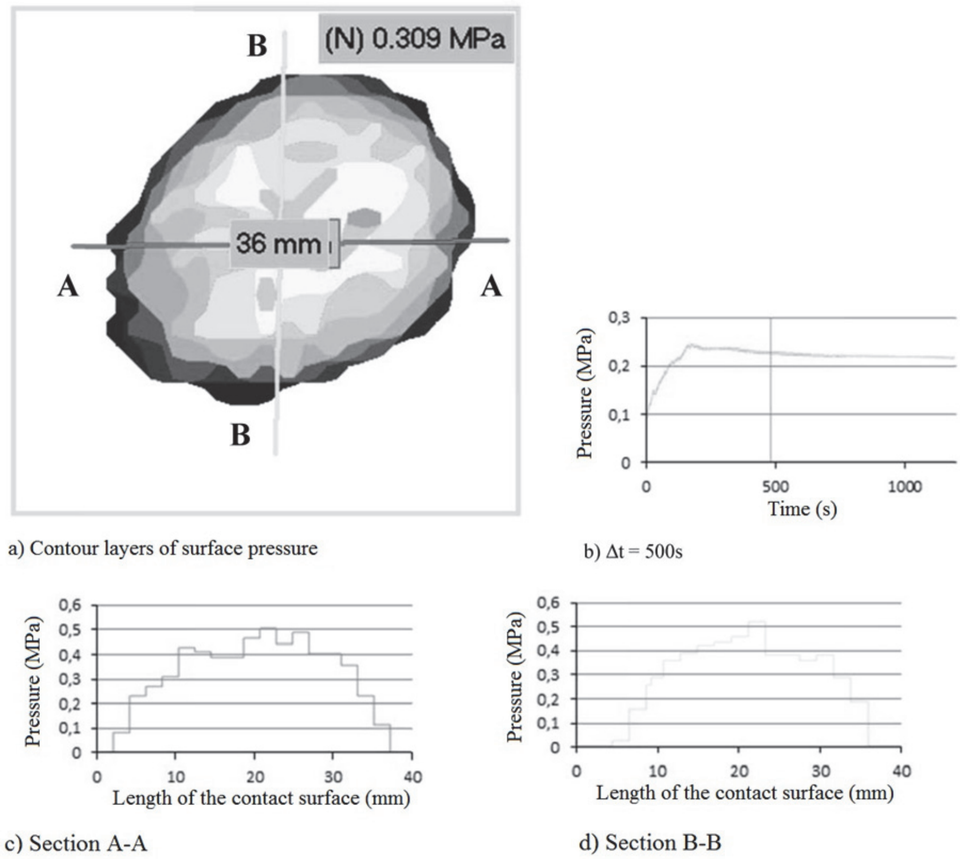

Figure 6. Contour layers and distribution of surface pressures in time Δt=500 s

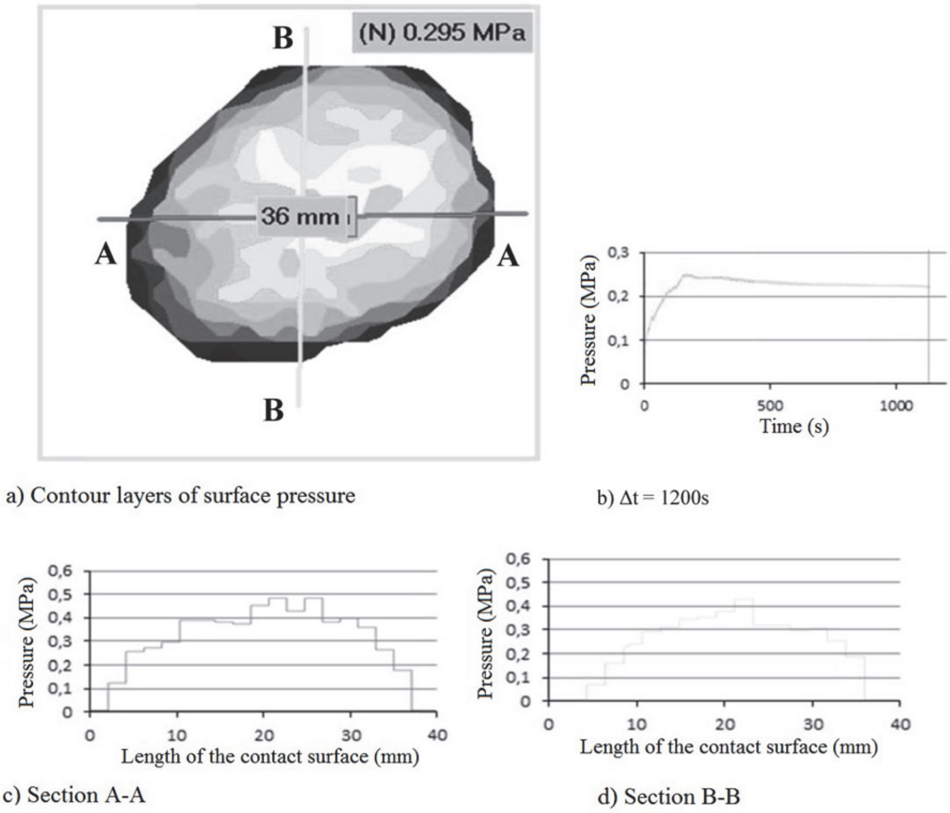

Figure 7. Contour layers and distribution of surface pressures in time Δt=1200 s

In the final phase of the creeping test, avocado fruit after 1200 seconds from the moment the test starts, the contour layers and surface pressures distribution did not explicitly change. Only a slight levelling of surface pressures took place in the contact zone of a fruit with a working element of the testing machine (fig. 7c,d) with maintaining an elyptic nature of distribution along the contact surface. The maximum values of the surface pressures were reduced to the value of p=0.475 MPa at the average pressures of p=0.295 MPa.

The change of the maximum values of surface pressures in the contact zone of avocado fruit with an element which loads the testing machine during the test is presented in figure 8. In the moment the test starts, average pressures obtained the value of p=0.574 MPa and afterwards gradually decreased to the level of p=0.509 MPa after 500 seconds and p=0.475 in the end of the test. It means that within 190 to 500 seconds the surface pressures were reducing in the rate of 209 10^{-}-6 $MPa \cdot s^{-1}$ whereas within 500 to 1200 seconds the rate was 49 10^{-}-6 $MPa \cdot s^{-1}$.

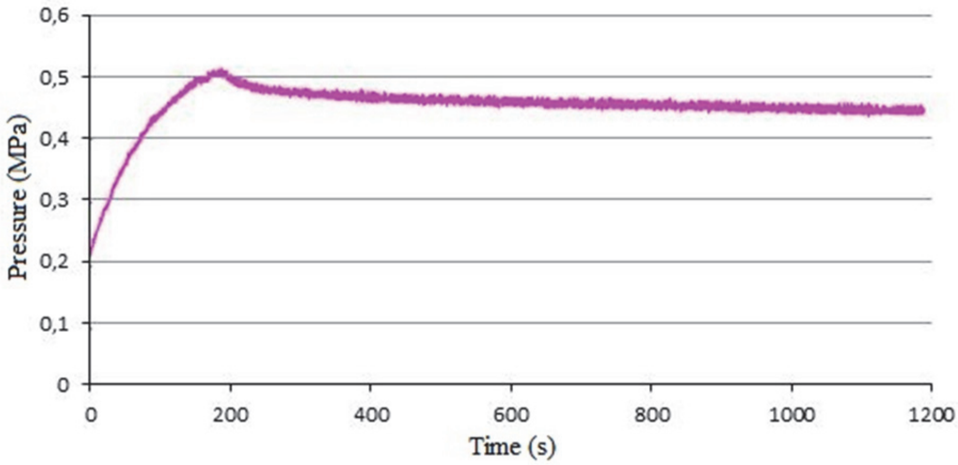

Figure 8. Maximum values of surface pressures as time function Δt=0 to 1200s

Conclusions

1. Value of the maximum surface pressures in the entire cycle of loading is reduced to the value of 0.574 MPa in the beginning of the test to 0.475 MPa in the end of the test, but in the initial stage of the test (190-500 seconds) the speed of thrusts reduction was four times higher than in the final stage.
2. The value of the average surface pressures in the entire cycle of loading is reduced from the value of 0.328 MPa to 0.295 MPa but in the initial stage of the test (190-500 seconds) the speed of thrusts reduction was thirty times higher than in the final stage.
3. Shift of the working element of the testing machine increases from the initial value l_0=478 mm to the value of l_1= 558 mm in the end of the cycle.
4. Distribution of thrusts on the contact surface of avocado with a loading element is not levelled during the creeping test.
5. The maximum values are in the central zone of the fruit contact with a loading element.

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Awocado, Itum group, obtained from:www.itum.com.pl

ROZKŁADY NACISKÓW POWIERZCHNIOWYCH DLA AWOKADO PRZY STAŁEJ WARTOŚCI OBCIĄŻENIA

Streszczenie. W przeprowadzonych badaniach zaprezentowano wyniki pomiarów nacisków powierzchniowych awokado odmiany Fuerte w teście ściskania promieniowego pomiędzy płaskimi płytami przy stałej wartości obciążenia z uwzględnieniem czynnika czasu. Test przeprowadzono przy wykorzystaniu maszyny wytrzymałościowej Instron 5566. Na dolnej płycie pod ściskanym owocem Awocado umieszczony został czujnik systemu Tekscan o numerze 5076. Pozwoliło ta na ciągłą obserwację warstwic nacisków powierzchniowych na powierzchni styku oraz wyznaczenie rozkładu nacisków powierzchniowych pomiędzy awokado z płytą dolną maszyny wytrzymałościowej. Wyznaczono warstwice i rozkłady nacisków powierzchniowych w różanych etapach testu pełzania. Wykazano, że maksymalne i średnie wartości nacisków powierzchniowych ulegają wyraźnemu zmniejszeniu w trakcie całego testu. Rozkład nacisków powierzchniowych ma kształt typowy dla zagadnień kontaktowych w sprężystym zakresie odkształceń, gdzie maksymalne wartości znajdują się w centralnej strefie styku i mają rozkład zbliżony do krzywej parzystej. Pod koniec testu nastąpiło tylko nieznaczne wyrównanie rozkładu nacisków na powierzchni styku Awocado z elementem roboczym maszyny wytrzymałościowej.

Słowa kluczowe: naciski powierzchniowe, awokado, ściskanie, czynnik czasu, pełzanie